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NAVAL FACILITIES ENGINEERING COMMAND WASHINGTON DC
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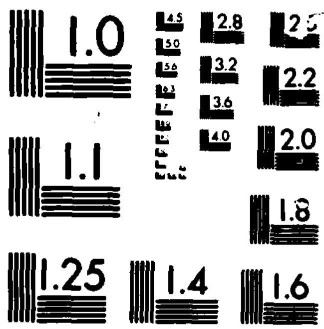

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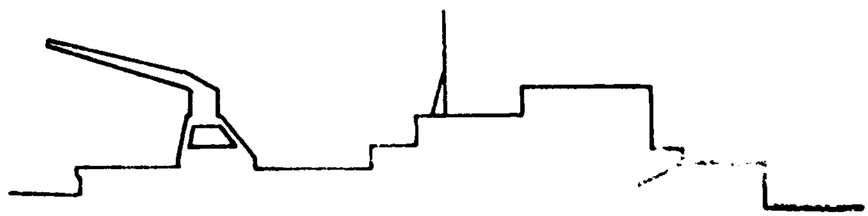
Preliminary Mooring Plan for The Empress II Barge

by

William N. Seelig

FPO-1-83(10)

Revised 29 June 1983



Ocean Engineering

CHESAPEAKE DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
WASHINGTON NAVY YARD
WASHINGTON, DC 20374

(1)

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The best method of mooring the Empress 11 and test vessel is by using a four-point mooring illustrated. Each point of the mooring will be a riser-type mooring with a buoy that can be used to moor the vessels because of their ease in handling. The mooring lines should: (1) stretch to act as shock (Con't)

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absorbers; (2) have strength; (3) float or have floats attached; (4) resist abrasion; (5) resist chemicals and (6) resist ultraviolet light. The type and dimensions of the lines will be determined in the final design stage.

Several sites have been examined. The sheltered waters in the Chesapeake Bay are recommended for testing small to medium class ships. The Bay area has the advantages that waves are fetch- and depth limited and that land areas will tend to reduce local wind speed slightly. The major disadvantages of the Bay area are the limited water depth and maneuvering room which poses a hazards to large vessels. Test sites in coastal ocean waters have the advantages of greater water depth and maneuvering room for the test ship. However, waves at the ocean sites will be generally larger than in the Bay. Testing in the summer will minimize wave effects. An ocean mooring should be in at least 70 feet of water to reduce non-linear wave forces in the mooring.

Physical model tests are recommended to determine forces in the mooring and to examine motions of the moored barge.

EXECUTIVE SUMMARY

The best method of mooring the Empress II and test vessel is by using a four-point mooring illustrated in the attached figure. Each point of the mooring will be a riser-type mooring with a buoy that can be used to restrain the barge and/or test ship. Synthetic lines should be used to moor the vessels because of their ease in handling. The mooring lines should: (1) stretch to act as shock absorbers; (2) have strength; (3) float or have floats attached; (4) resist abrasion; (5) resist chemicals and (6) resist ultraviolet light. The type and dimensions of the lines will be determined in the final design stage.

Several sites have been examined. The sheltered waters in the Chesapeake Bay are recommended for testing small to medium class ships. The Bay area has the advantages that waves are fetch- and depth-limited and that land areas will tend to reduce local wind speeds slightly. The major disadvantages of the Bay area are the limited water depth and manuevering room which poses a hazard to large vessels. Test sites in coastal ocean waters have the advantages of greater water depth and manuevering room for the test ship. However, waves at the ocean sites will be generally larger than in the Bay. Testing in the summer will minimize wave effects. An ocean mooring should be in at least 70 feet of water to reduce non-linear wave forces in the mooring.

Physical model tests are recommended to determine forces in the mooring and to examine motions of the moored barge.

OPERATIONAL CONDITIONS

The following operational conditions are tentatively recommended:

a. Significant wave heights less than 5 feet (This height should be better defined as the highest waves when personnel can work and safely leave the barge. Further model studies and prototype experience will help define this limit).

b. Wind speeds less than 28 knots (below a "Moderate Gale")

EVACUATION

Personnel should seriously consider leaving the barge and have the barge towed into sheltered water from an operation-only mooring when the following are expected:

a. Significant wave heights of 5 feet or greater; or

b. Winds higher than 28 knots (a "Moderate Gale" or higher).

These limitations can be relaxed if the freeboard can be increased by the crew and if an ocean storm-hardened mooring is included.

SURVIVAL MOORING

The barge should be moved out of an operation-only mooring and put into the survival mooring if the wind speeds greater than 28 knots are expected.

DOWNTIME

Based on the above advice and available statistics, testing will not be possible for the following times:

Predicted Downtime When Testing Is Not
Recommended Due To Adverse Wind and Wave Conditions
(HOURS PER MONTH)

Location	Due to Waves	Due to Wind	Total
Chesapeake Bay (all year)	14	52	52
Dam Neck (May-July)	12	9	12 to 21
Caribbean (all year)	80	34	80 to 114

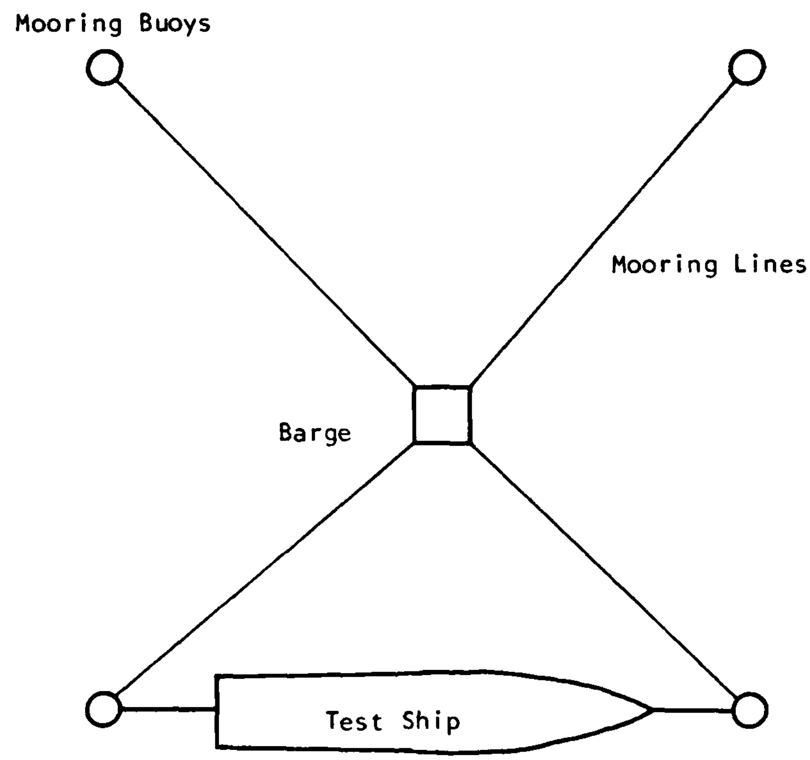
MOORING DESIGN

Each corner of the four-point mooring will consist of a mooring buoy, a riser chain and an anchor. The buoy should be large and 4-inch Grade 3 riser chain is recommended. A deadweight anchor will require a weight of several hundred tons made of scrap metal and concrete. The details of the final anchor design will depend on sediment characteristics at the site and the design loads determined from the model studies.

WORKING COST ESTIMATE

The approximate cost of the installed four-point mooring is $950K in FY83 dollars. Exact cost will depend on detailed design and location, as well as year of installation. The mooring line costs will have to be determined during final design.

CHESAPEAKE DIVISION **Naval Facilities Engineering Command NDW** **DISCIPLINE**	**PROJECT:** Empress II Mooring **Station:** **E S R:** **Contract:**
Calcs made by: SEELIG **date:** 4/8/83 **Calcs ck'd by:** **date:**	**Calculations for:** Mooring Lay-out



Mooring Configuration for a Moored Test Ship

Note: Test ship leaves and the barge goes to a single-point mooring during storm conditions.

GPO 885-653

Preliminary Mooring Plan for the Empress II Barge

by

William N. Seelig
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Chesapeake Division
Ocean Engineering & Construction Project Office

1. Introduction

The Empress II will be a test barge 120 feet long, 105 feet wide, 12 feet high with an operational freeboard of ≈3 feet. The barge holds a cone-shaped antenna 120 feet high with a maximum diameter of 220 feet. The barge will be used in sheltered water as well as in coastal ocean waters.

2. Problem

The problem is how to safely moor the barge during testing and for "survival" conditions. Factors that need to be considered are safety of the crew and equipment, operational requirements and cost.

3. Approach

This report presents preferred preliminary mooring designs and recommends methods of using these moorings. These designs were formulated after the following steps were taken:

a. reviewed previous work (Reference 1);
b. examined wind, wave and current statistics (References 2,3 and 4);
c. determined operational requirements of the system;
d. formulated preliminary designs and made cost estimates;
e. performed computer analyses and limited physical model studies; and
f. selected the most promising designs.

4. Operational Requirements (per meeting of PM-23, NAVSEA & CHESDIV)

During operation the barge will have a freeboard of ≈3 feet and the amount of metal above this level should be minimized. During some tests the test ship will pass in the vicinity of the moored barge. During other tests the ship will be moored for as long as two weeks and moved into various positions. The barge should survive extreme storms in case it cannot be towed.

5. Conceptual Design

The design layout shown in Figure 1 (Reference 1) is ideal because it allows the barge (which has no internal propulsion) to position itself by letting out and pulling in on the various mooring lines. The test ship can also go into a bow-stern mooring between two of the four-point moorings (Figure 1).

Several of the possible designs for each point on the mooring are shown in Figure 2. The deadweight anchor type mooring with riser chain and buoy is recommended (Figure 2 D). Advantages of this last type of mooring are:

1) highly reliable
2) reasonable cost
3) design can easily be applied to a number of sites
4) simple design
5) easy to install (the deadweight anchor can be floated to the site)
6) low maintenance
7) no ground legs to tangle with ships anchors

The details of the anchor design will have to be worked out in final design to suit the selected site. Preliminary calculations show that it will have to be several hundred tons. However, costs can be kept reasonable if concrete and scrap metal are used to form a deadweight anchor.

Much of the design effort will have to be devoted to designing the lines used to moor the barge to the mooring, because this will be the weakest link in the system. These lines should resist the environmental forces, absorb dynamic loads, be easy to handle, resist wear and be non-ultraviolet sensitive. Working lines should float to allow easy usage.

6. Wave Statistics

Waves play an important role in the design of the moorings and in the operation of the barge for several reasons. First, at a 3-foot freeboard it will only take a relatively small wave to place the decks awash making operations hazardous and endangering the crew. During high waves the freeboard should be increased by deballasting and/or by moving the barge to sheltered waters. Second, waves can cause high mooring loads in a stiff mooring (Reference 5). Third, waves may damage the antenna through rapid accelerations and motions of the barge.

Model studies still need to be performed to determine under which wave conditions the crew can safely work and what is the maximum conditions under which evacuation can take place.

The Chesapeake Bay has the best wave climate of the sites proposed with significant wave heights 6 feet or higher less than 10 hours per month throughout the year (Figure 3). Dam Neck (off the mouth of the Chesapeake Bay) could also be used for testing during the months of May through July, when the chance of high waves is minimized (Figure 4). The best time to conduct tests in the Caribbean would be April through June or October through November (Figure 3).

The above statistics lead to the following conclusions: operate whenever possible in the Chesapeake Bay; operate off of the mouth of the Chesapeake Bay in the summer; and moor the barge in the Chesapeake Bay during major storms to reduce the possibility of problems caused by waves (see Figure 5 for wave height statistics in cumulative form and Table 1).

Mariners have long recognized that even small waves in shallow water are much more dangerous than larger waves in deep water. This is because as waves move into shallower water they shoal. These non-linear, shoaled waves produce a variety of problems, such as very high mooring loads (Reference 6). Mooring chain loads reach 1 million pounds (Reference 5) for the worst possible breaking wave conditions that can occur in 50 feet of water for the Empress II (wave period = 12 seconds,

see Figure 6). However, these monochromatic breaking two-dimensional wave conditions used in the laboratory tests are highly unlikely in nature. The natural wave trains have a three-dimensional nature and waves higher than the significant wave height occur only about 13% of the time.

The following method was used to select a maximum ocean design wave height for the various water depths of interest:

a. The maximum possible level of wave energy was determined at various ocean water depths using methods in Reference 7 with a deepwater design wave period of 12 seconds;

b. The wave energy was converted into a significant wave height and corrected for non-linear effects using techniques described in Reference 8; and

c. The maximum wave height was taken as 1.8 times the significant wave height (Reference 9).

The resulting ocean design wave heights for various water depths are given in Table 2, together with design wave forces in a riser-type chain mooring (see Figure 6). Note that the design force increases as the barge is moored in shallower ocean water, even though the design wave height decreases (Figure 6).

7. Winds

Winds are important because the force on the barge increases approximately as the square of the wind velocity and very high velocities are possible. Figure 7 shows wind speed statistics for extreme events in the Chesapeake Bay area. Some extreme winds and resulting forces are:

Wind (knots)	Return Period (years)	Force on Barge (Kips)
120	100	300*
105	40	225*
90	25	100

*includes wave forces in the Chesapeake Bay (33% of static force)

Winds are also important during operation because forces and moments are induced in the antenna, significant mooring line forces may occur and waves and wind will produce green water over the deck. The probabilities of various winds being exceeded, in terms of hours per month, is given in Table 3 and in cumulative form on Figure 8 and by month on Figure 8A.

8. Currents

Reference 1 shows that current forces are not very large, so an operational current of 1.5 knots and survival current of 2.0 knots are used in this study.

9. Working Cost Estimate

A four-point mooring placed in the Chesapeake Bay area will cost approximately $950K as outlined in Appendix A. Costs of the lines to moor the Empress II and test vessel to the four-point mooring will have to be worked out in final design. Physical model studies are recommended to provide information on mooring line forces due to waves.

10. Summary and Recommendations

The Empress II barge and test vessel can conviently be moored as shown in Figure 1. In this configuration the barge is moored in a four-point mooring. The barge is then moved around for testing by letting in and out on the barge mooring lines. The vessel to be tested is in the meantime put into a two-point bow and stern mooring. The Empress II is moored with heavy lines to one of more of the buoys during poor weather.

The best place to conduct tests would be in sheltered water, such as the Chesapeake Bay. However, wind and wave conditions are quite mild off the Dam Neck area in the summer (especially May through July), so larger vessels requiring deep water or extra maneuvering room could be tested in the coastal Atlantic. Other sites, such as the Caribbean, could also be used.

Test sites exposed to ocean waves should be selected to have water depths of at least 70 feet. This will minimize forces due to waves because waves in deeper water are more linear. Water depths much greater than 100 feet should also be avoided to allow easy diver inspection of the moorings.

The two critical items requiring careful design are: (a.) the mooring lines between the Empress II and the buoys and (b.) the anchor. Large 1/28 scale model tests are recommended to aid in the final design of this mooring system.

Embedment anchors are a lower cost method of mooring the Empress II for temporary operation of less than a year.

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9. U.S. Army Corps of Engineers, Coastal Engineering Research Center, "Shore Protection Manual", Ft. Belvoir, Va., 1977.
10. Seelig, W. and Walter, M., "Model Study of Mooring Forces for a Barge Moored with Synthetic Line", CHESDIV Report FPO-1-83(15), May 1983.

Table 1. Hours per Month Various Wave Heights are Exceeded

Location	Significant Wave Height 3'	4'	5'	6'	10'
Chespeake Bay (all year)	90	40	14	6	1
Dam Neck (May-Jul)	90	30	12	4	1
(all year)	260	140	80	44	10

Table 2. Design Conditions for a Storm-Hardened Ocean Mooring

Water Depth (ft)	H_s (ft)[4]	H_{max}[1] (ft)	Wave[5] Force (kips)	Wind[2] Force (kips)	Current[3] Force (kips)	Total Force (kips)
50	14.8	27	500	100	55	655
75	16.2	29	130	100	55	285
100	18.7	34	65	100	55	220

[1] H_{max} is used for design and here taken as 1.8 times H_s. Higher waves are possible, but unlikely.

[2] A 90 knot wind is used for design; this has a 25 year return period

[3] A 2.0 knot current is used for design.

[4] $\alpha = 0.0081$; R=1.0

[5] Tested with no hawser. A properly designed mooring hawser will reduce these wave forces.

Table 3. Hours per Month Various Wind Speeds are Exceeded

Location	Wind Velocity in Knots		
	28	30	35
Chesapeake Bay (all year)	42	25	11
Dam Neck (May-Jul)	9	6	3
Puerto Rico (all year)	30	25	14

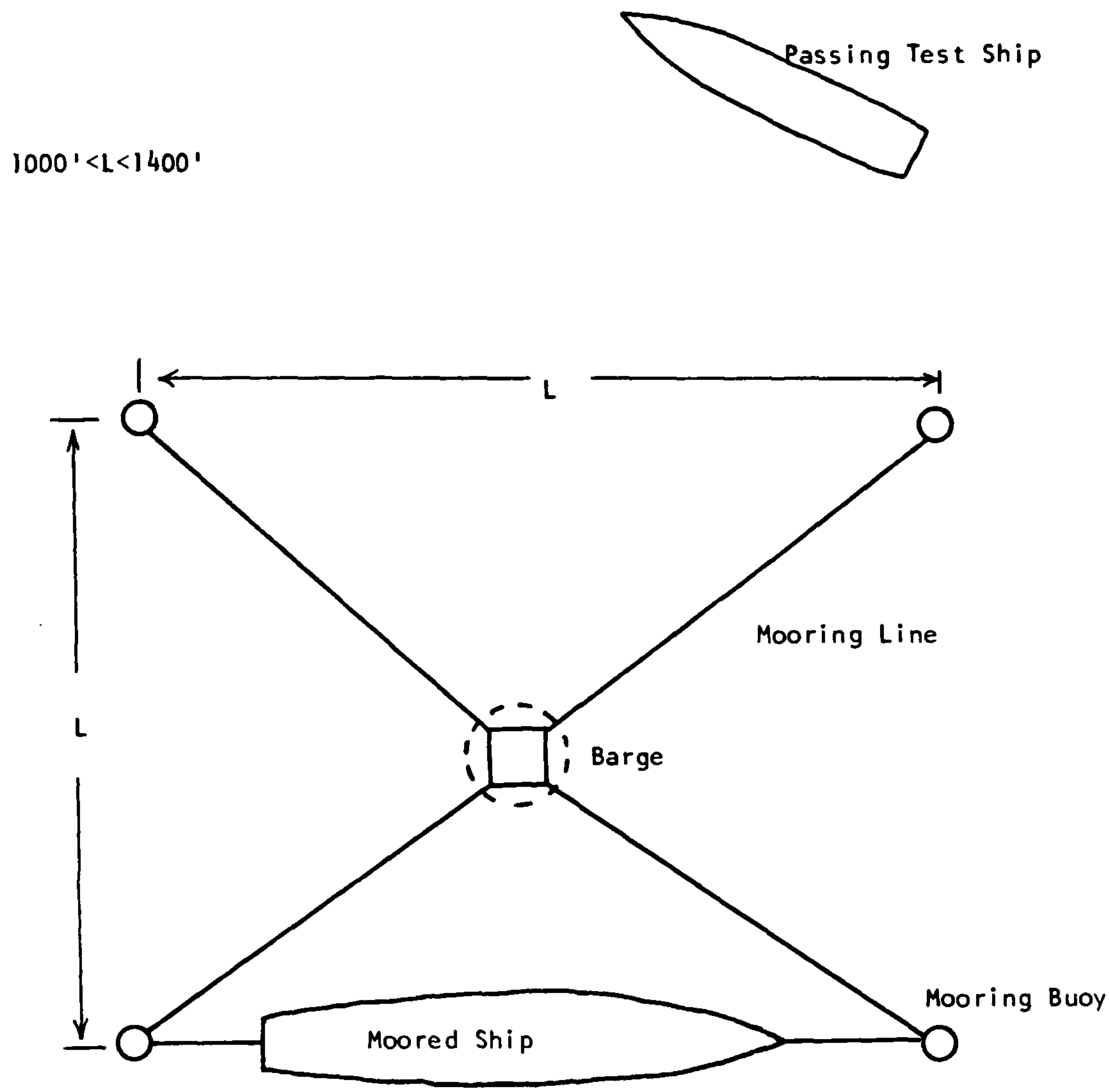
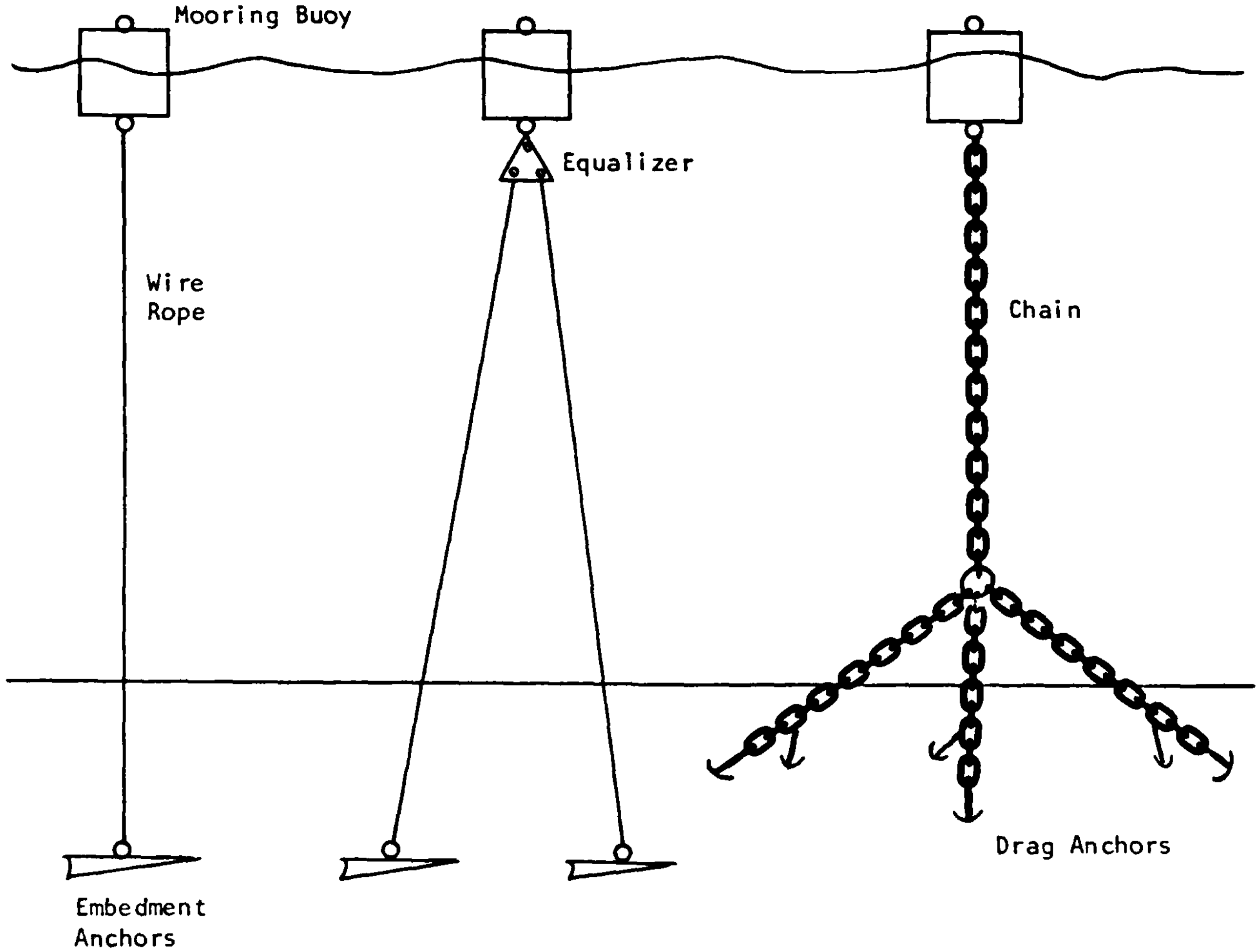


Figure 1. The Mooring Plan

CHESAPEAKE DIVISION Naval Facilities Engineering Command NDW DISCIPLINE	PROJECT: Empress II Station: E S R: Contract:
Calcs made by: Seelig date: 7/11/83 Calcs ck'd by: date:	Calculations for: Mooring Types



A) Single Embedment Anchors

B) Dual Embedment Anchors

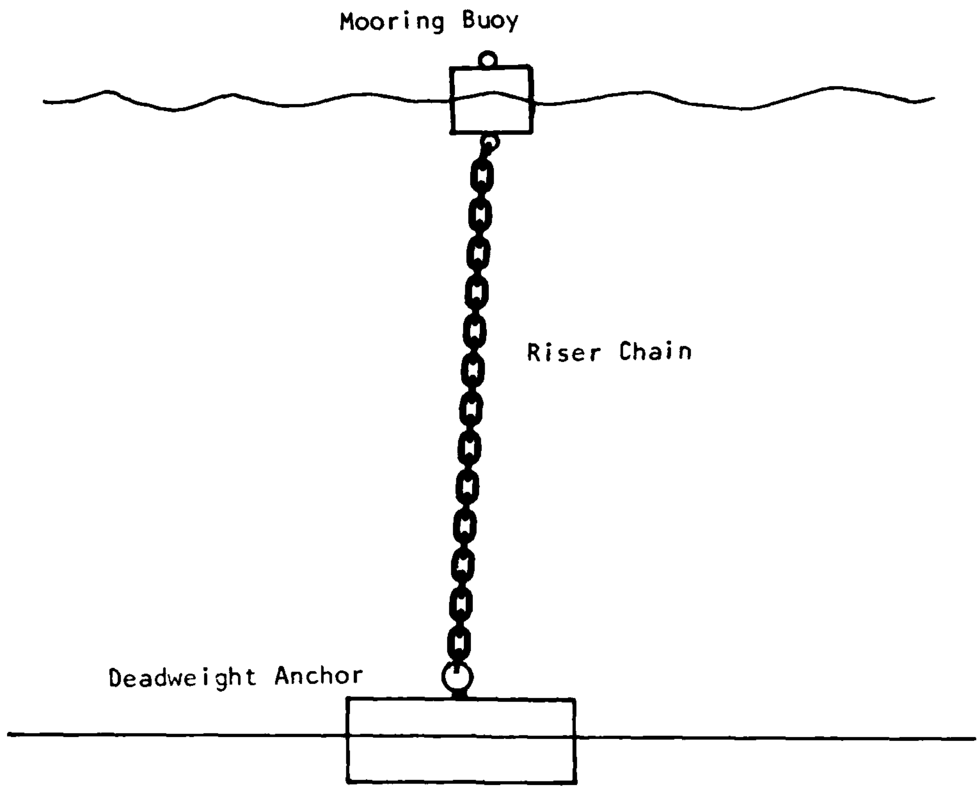
C) Multiple Drag Anchors with Chain Riser

Figure 2. Mooring Types

CHESAPEAKE DIVISION
Naval Facilities Engineering Command NDW
DISCIPLINE

Calcs made by: Seelig **date:** 6/27/83
Calcs ck'd by: **date:**

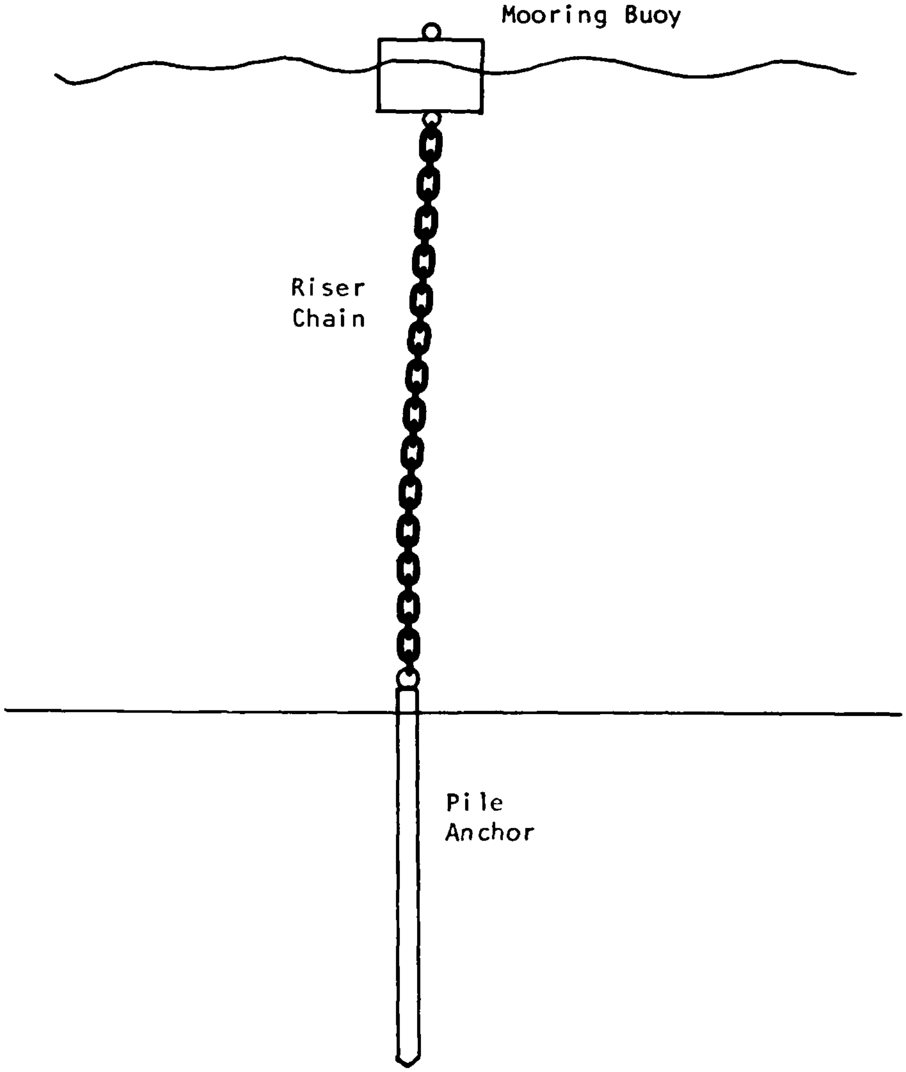
PROJECT: Empress II
Station:
E S R: **Contract:**
Calculations for: Mooring Types (cont)



D) Deadweight Anchor & Riser Mooring

Figure 2. Mooring Types (cont.)

CHESAPEAKE DIVISION		PROJECT: Empress II	
Naval Facilities Engineering Command NDW		Station:	
DISCIPLINE		E S R:	Contract:
Calcs made by: Seelig	date: 7/11/83	Calculations for: Mooring Types (cont.)	
Calcs ck'd by:	date:		



E) Pile Anchor & Riser Mooring

Figure 2. Mooring Types (cont)

CHESAPEAKE DIVISION Naval Facilities Engineering Command NDW DISCIPLINE	PROJECT: Empress II Station: E S R: Contract:
Calcs made by: SEELIG date: 4/1/83 Calcs ck'd by: date:	Calculations for: Seasonal Wave Statistics

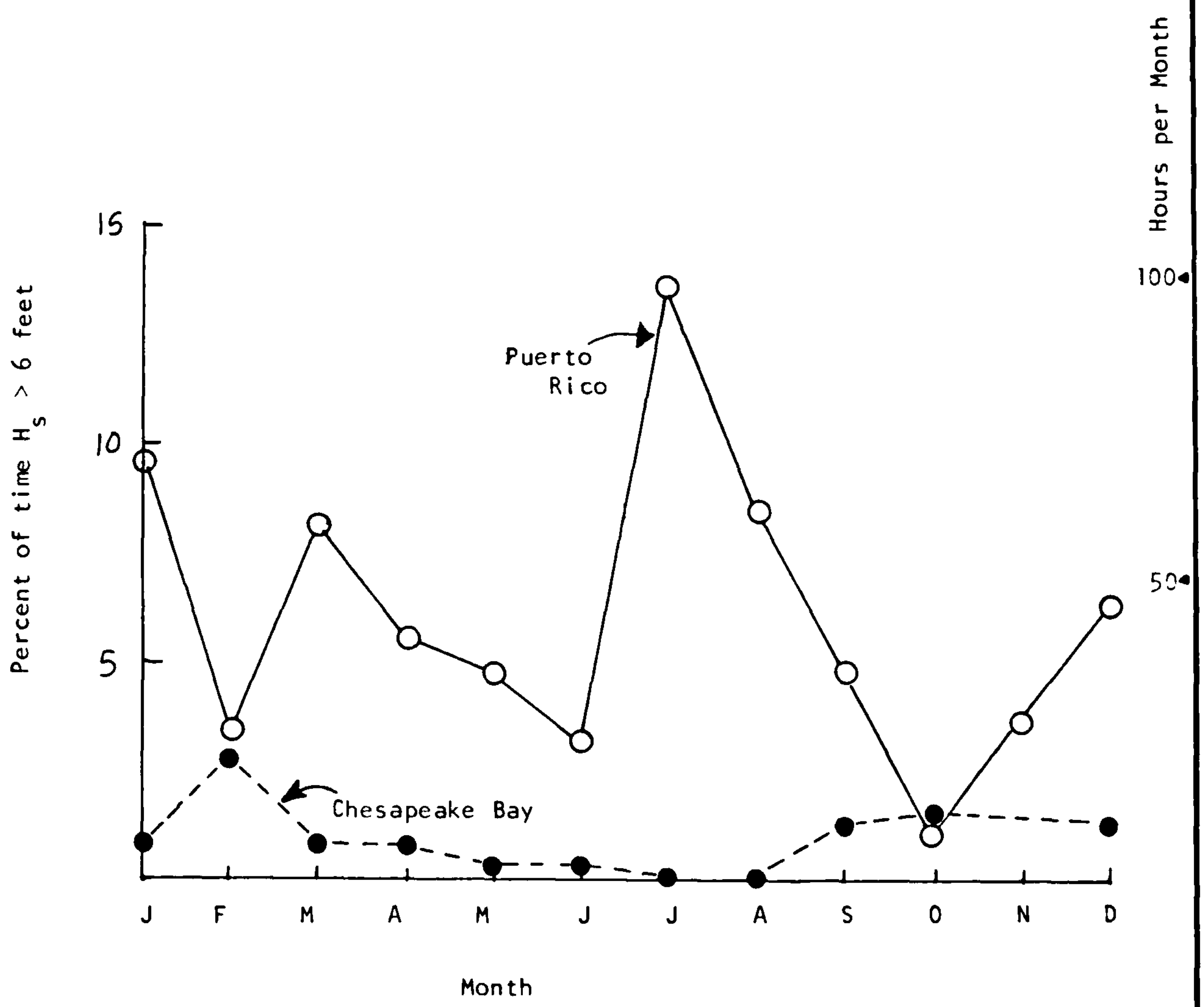


Figure 3. Percent of time the significant wave height is greater than 6'

CHESAPEAKE DIVISION	**PROJECT:** Em[illegible] II
Naval Facilities Engineering Command NDW	**Station:**
DISCIPLINE	**E S R:** **Contract:**
Calcs made by: Seelig **date:** 6/3/83	**Calculations for:** Wave Heights
Calcs ck'd by: **date:**	

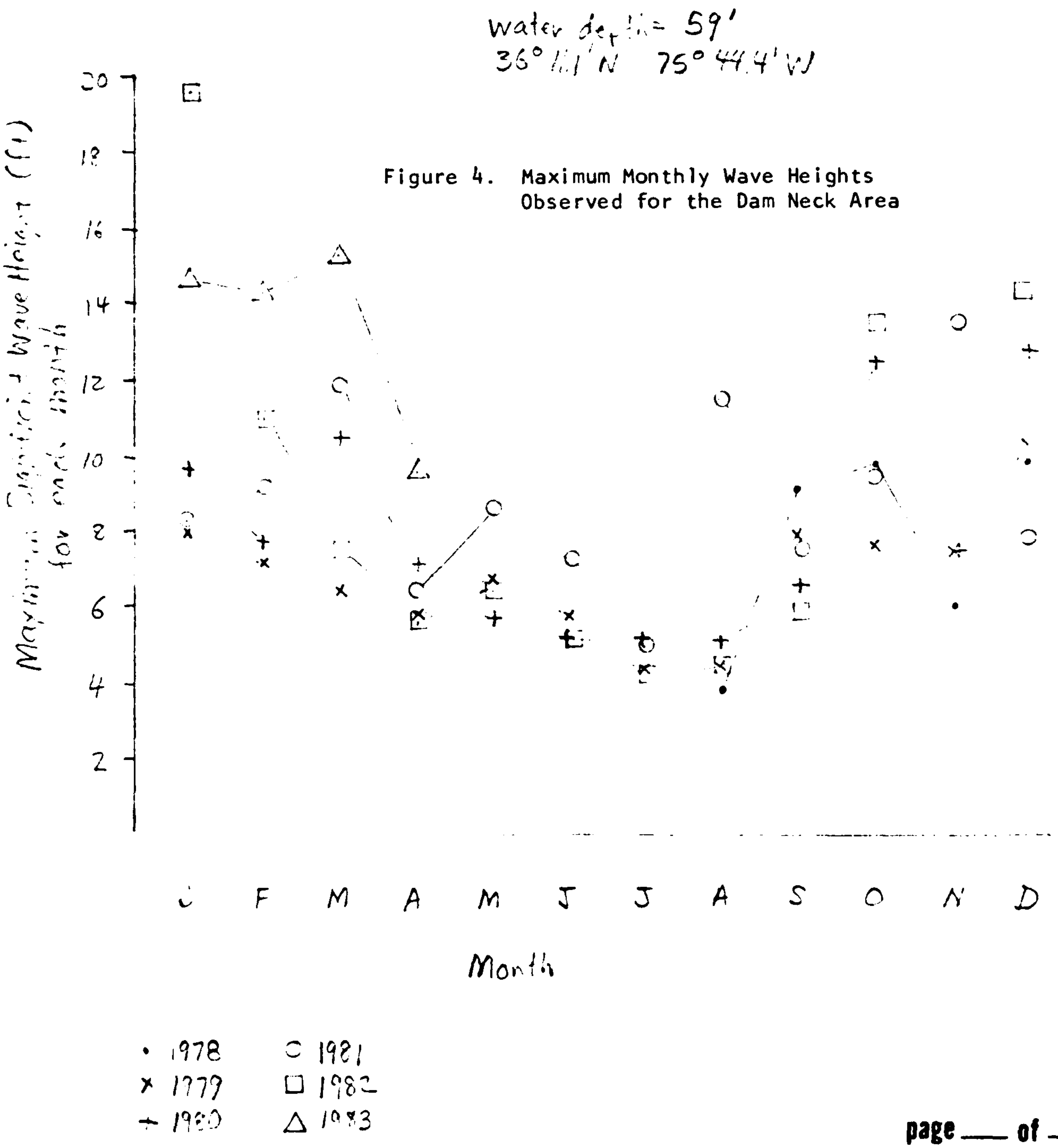


Figure 4. Maximum Monthly Wave Heights
Observed for the Dam Neck Area

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GPO 885-853

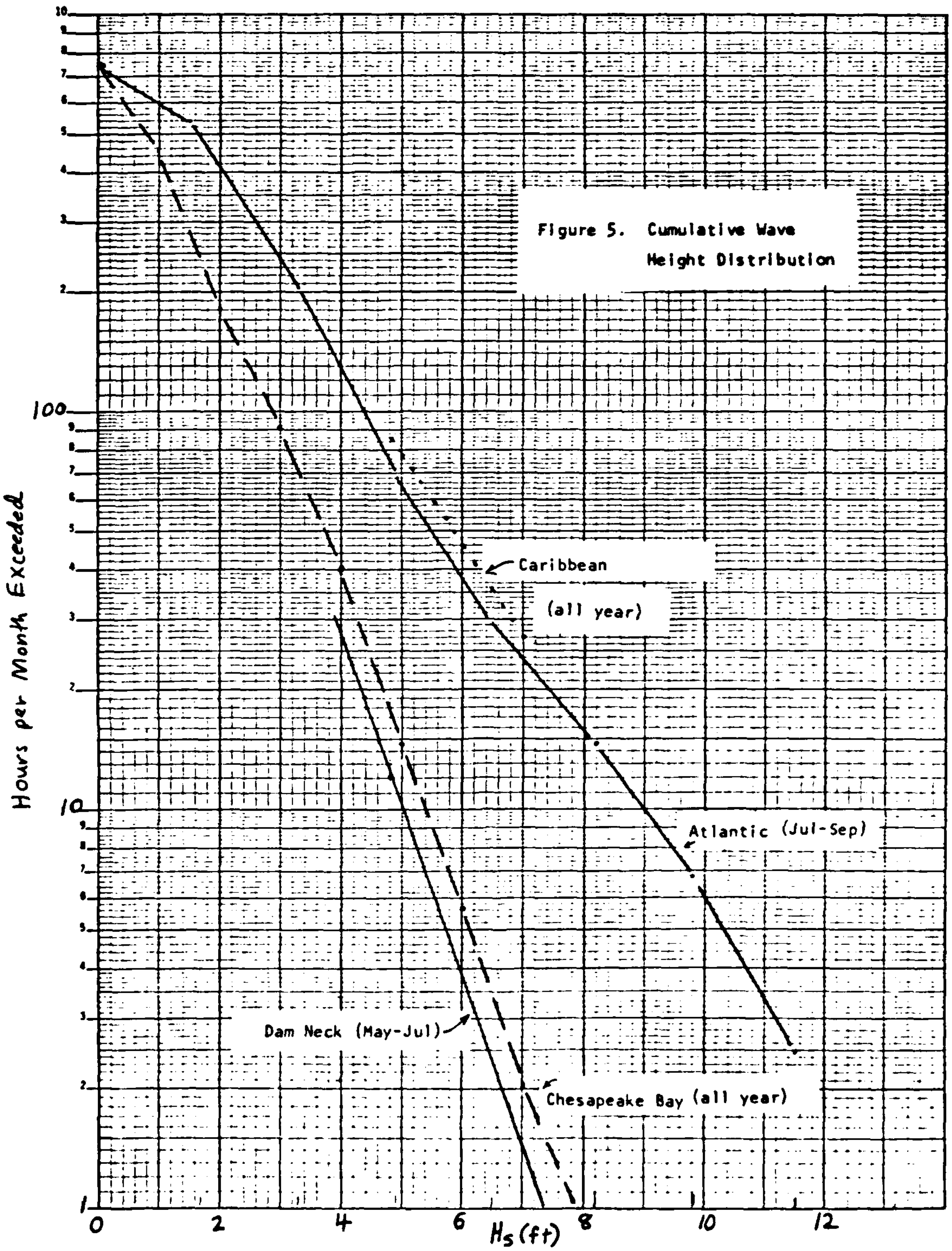
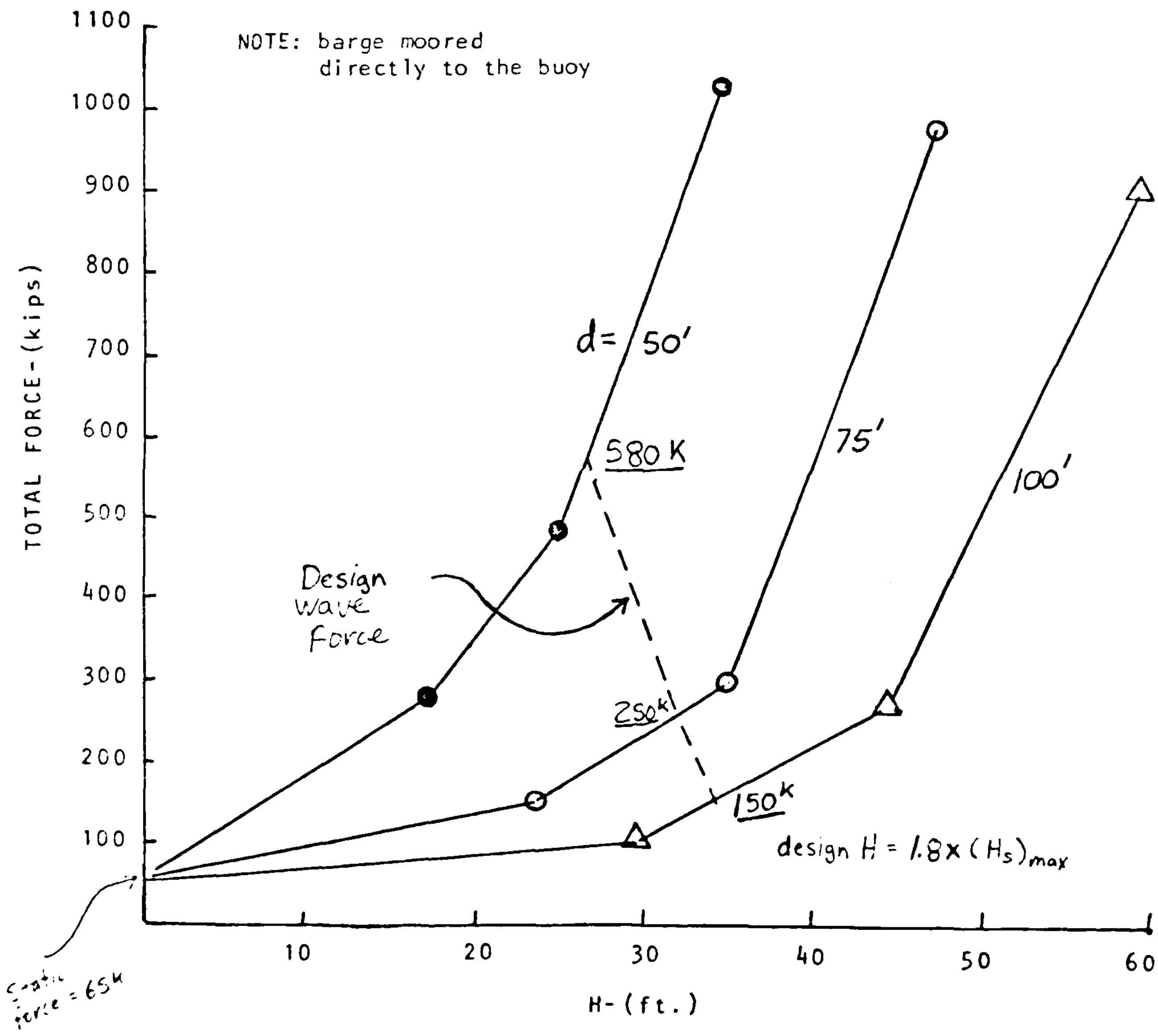


Figure 5. Cumulative Wave Height Distribution

CHESAPEAKE DIVISION Naval Facilities Engineering Command NDW DISCIPLINE	PROJECT: Empress II Station: E S R: Contract:
Calcs made by: Seelig date: 3/24/83 Calcs ck'd by: date:	Calculations for: Wave Forces on Mooring 1/100 Scale Froude Model

T = 12 sec



Barge 105' x 120' x 12'

page ___ of ___

Figure 6. Design Waves and Wave Forces for a Storm Hardened Mooring in the Ocean

GPO 888-853

CHESAPEAKE DIVISION	PROJECT: Empress II
Naval Facilities Engineering Command NDW	Station:
DISCIPLINE	E S R: Contract:
Calcs made by: Seelig date: 4/4/83	Calculations for: Wind Return Periods
Calcs ck'd by: date:	

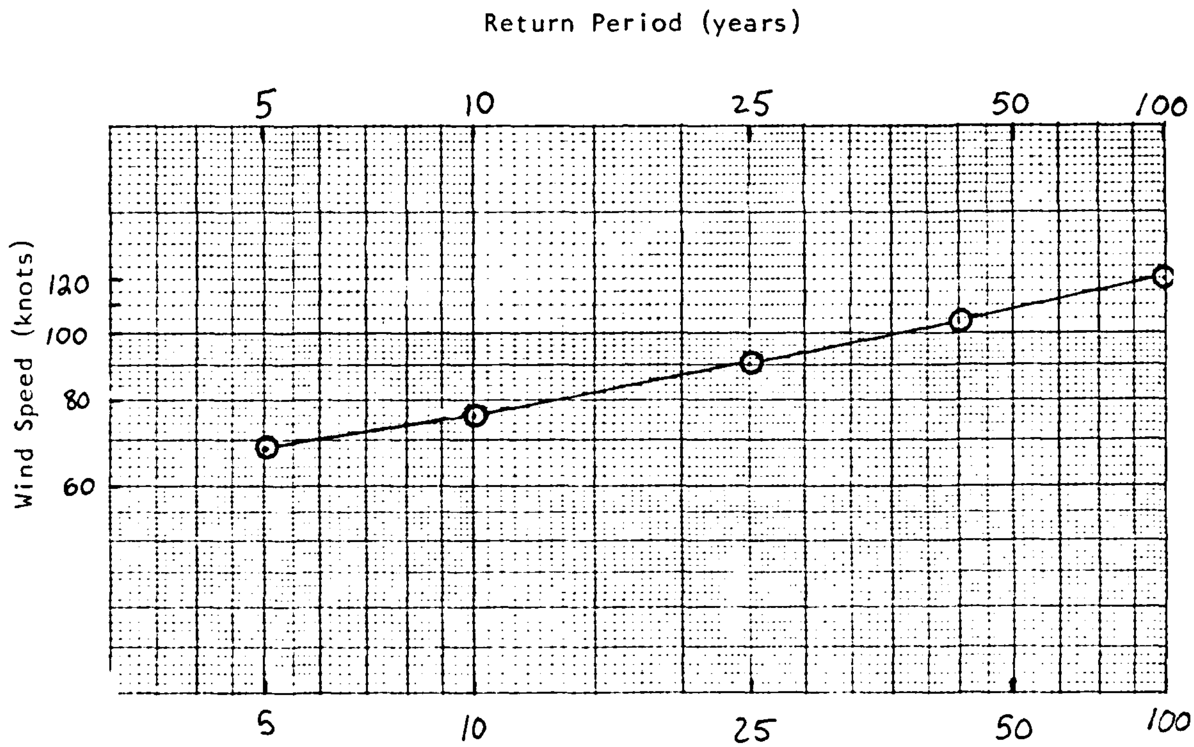


Figure 7. Extreme Wind Return Periods for the Chesapeake Bay Area

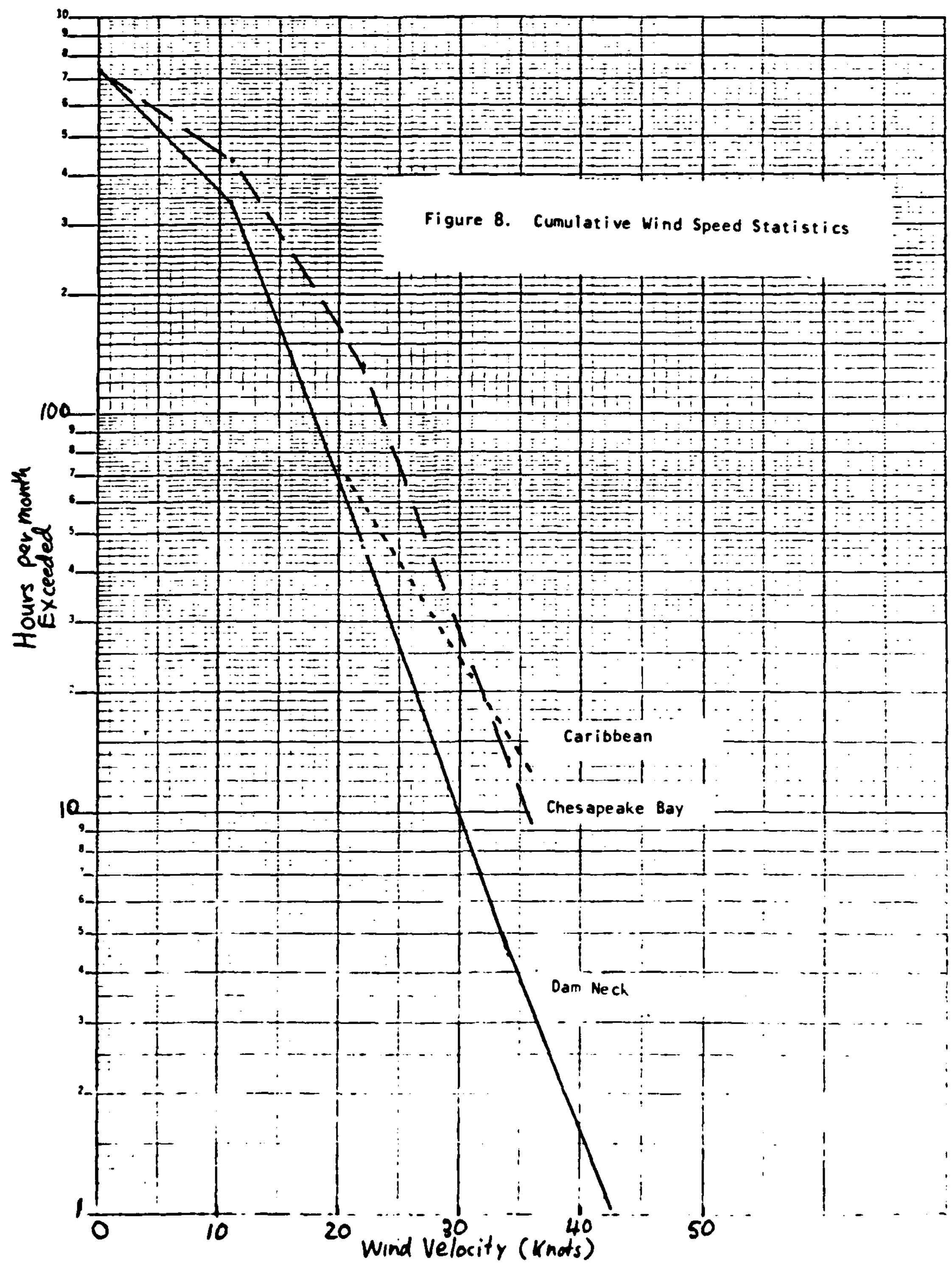
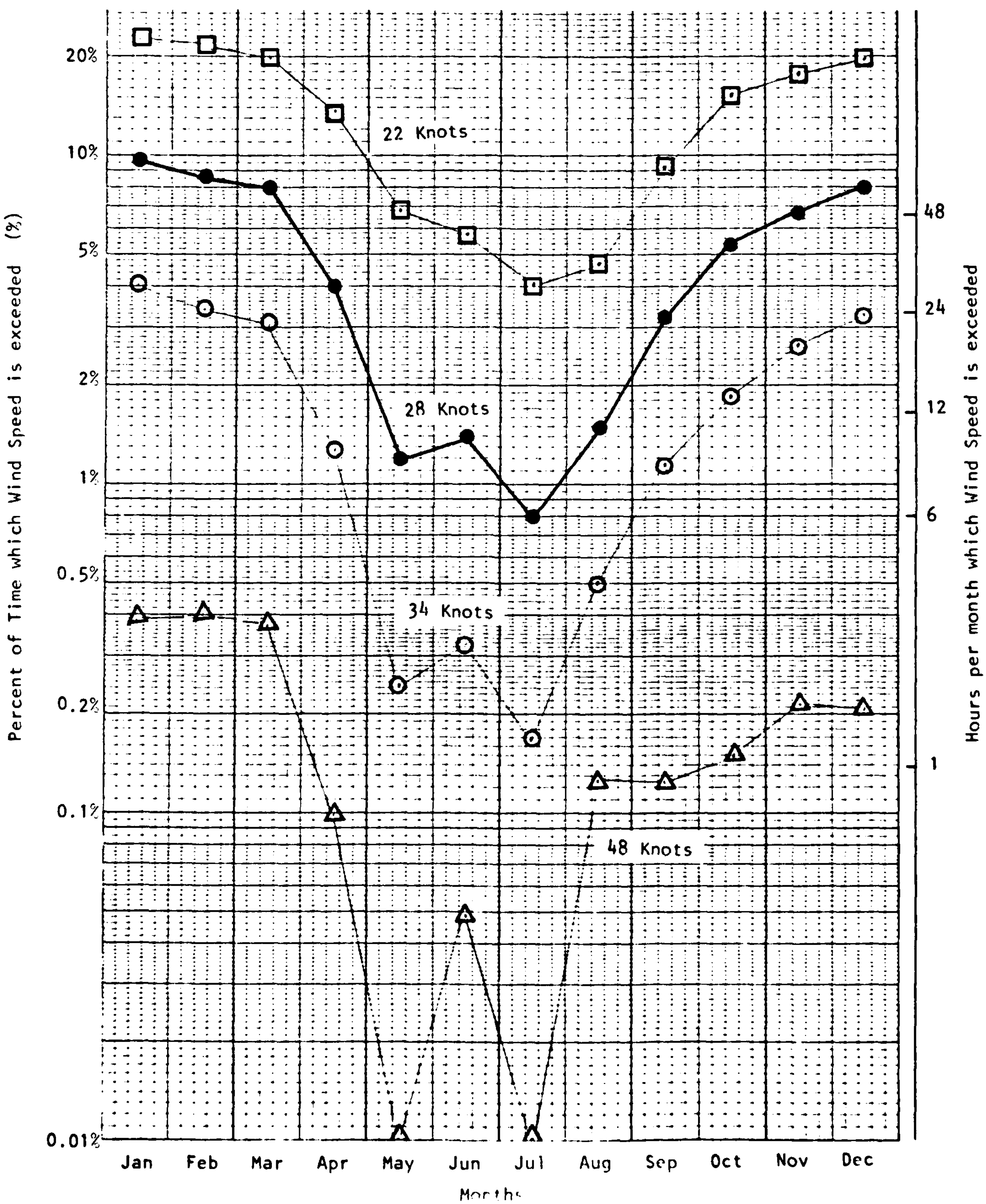


Figure 8. Cumulative Wind Speed Statistics
Caribbean
Chesapeake Bay
Dam Neck
Hours per month Exceeded
Wind Velocity (Knots)
1
10
100
0
10
20
30
40
50

Figure 8A. Wind statistics by month for Norfolk



Appendix A. Working Cost Estimate
(Fy83 dollars)

<u>Each Corner of the Mooring</u>

Buoy		\$50 K
Riser (4" Grade 3 chain)		\$47 K
Anchor		
Concrete 110 yd^3 x \$85/yd^3 =	\$10 K	
Forming	\$ 8 K	
Steel \$950/ton x 18 tons =	\$17 K	
Welding	\$ 2 K	
Misc	\$13 K	
TOTAL		\$50 K
Sub-Total		\$147 K

<u>Total Cost of Mooring Buoy System</u>

Four-Point Mooring Materials	4 x \$147 K	\$588 K
Installation & Contingency		\$342 K
Total		\$930 K

Appendix B. Ship Forces on Moorings

If a ship is to be moored while testing, then wind and currents on the ship will transmit forces into the moorings. These are preliminary calculations to indicate the amount of force that must be with held for a LHA-1 ship.

1.5 Knot Current, 28 Knot WIND

GIVEN Ship Designation : LHA-1

Water Depth WD = 55 feet

(_ @ High Tide or _ @ Low Tide)

*Current Speed V_c = (1.5) knots x 1.689 = 2.53 ft/sec

(Use average value of current profile between waterline and ship's keel)

*Wind Speed V_w = (32) mph x 1.467 = 47.3 ft/sec

(@ 33 feet above water level) 28 knots

* If current speed and wind speed are unknown, refer to Table 1.

In calculations below, use ft/sec quantities.

ASSUMPTIONS

a) Water density is constant and equals 1.9876 lb-sec^2/ft^4 @ 68°F.

b) Air density is constant and equals 0.00237 lb-sec^2/ft^4 @ 68°F.

PROCEDURE

A. From Table 2:

Length Overall LOA = 820 feet _ Normal

Length at waterline LWL = 765 feet X Hull-Dominated

Beam B = 106 feet

Load condition:		Fully Loaded	1/3 Stores/Cargo /Ballasted	Light
Draft	T =	feet	21.3 feet	feet
Below water end area	A_b=BT =	sq.ft.	21000 sq.ft.	sq.ft.
End-projected wind area	A_e =	sq.ft.	11250 sq.ft.	sq.ft.
Side-projected wind area	A_s =	sq.ft.	74950 sq.ft.	sq.ft
Displacement	D =	long tons	30020 long tons	long tons

B. Basic constants:

ARM = 0.48 LOA = = 394 feet

**S = $(1.7\ T\ LWL) + (\frac{35D}{T})$ = = 27,700 sq.ft.

** For a normal vessel S should be multiplied by a factor of 0.95.

$F_{yc} = C_{yc}\ 1/2\ \rho_c\ V_c^2\ LWL\ \ T = C_{yc}\ 1/2\ (1.9876)\ (2.53)^2\ 765\ (21.3) = C_{yc}\ \ 1.04 \times 10^5$

$M_c = C_{xyc}\ 1/2\ \rho_c\ V_c^2\ LWL^2\ T = C_{xyc}\ 1/2\ (1.9876)\ (2.53)^2 (765)^2 (21.3) = C_{xyc}\ \ 7.9 \times 10^7$

$F_{xw} = C_{xw}\ 1/2\ \rho_w\ V_w^2\ A_e = C_{xw}\ 1/2\ (0.00237)\ (47.3)^2\ 11250 = C_{xw}\ \ 2.98 \times 10^4$

$F_{yw} = C_{yw}\ 1/2\ \rho_w\ V_w^2\ A_s = C_{yw}\ 1/2\ (0.00237)\ (47.3)^2\ 74950 = C_{yw}\ \ 1.99 \times 10^5$

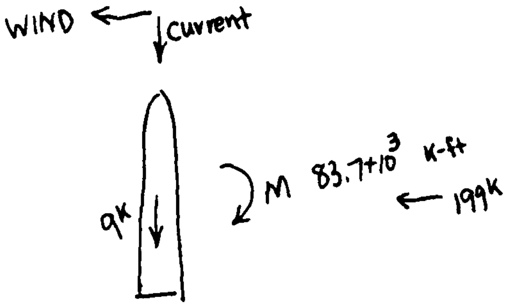
$M_w = C_{xyw} 1/2\ \rho_w\ V_w^2\ A_s\ LWL = C_{xyw} 1/2\ (0.00237)\ (47.3)^2\ 74950\ (765) = C_{xyw}\ \ 1.52 \times 10^8$

FIGURE 8a

Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

1.5 Knot current, 28 Knot WIND

C. TRIAL # LHA-1 $^{WD}/T$ = 2.6



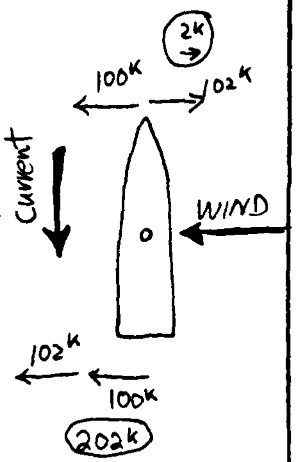
WIND/CURRENT ANGLE θ_T = ______ °

*CURRENT ANGLE θ_c = 0 °

*WIND ANGLE θ_w = 90' °

*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.



Coefficients for this θ_c, θ_w and $^{WD}/T$:

C_{xca} = 0.35 (Figure 2)

C_{yc} = 0 (Figure 3)

C_{xcb} = $|C_{yc} \text{ Cos } \theta_c| \text{Cos } \theta_c$ = 0 = ______

C_{xyc} = 0. (Figure 4)

C_{xw} = 0. (Figure 5) __Normal, or __Hull-Dominated

C_{yw} = 1.0 (Figure 6)

C_{xyw} = -0.035 (Figure 7)

Forces and Moments:

$F_{xc} = 1/2\ \rho_c\ V_c^2\ [(C_{xca}\ S\ \frac{B}{LWL}) + (C_{xcb}\ A_b)]$

$F_{xc} = 1/2\ (1.9876)\ (2.53)^2\ [(0.35 \times 27700\ \frac{106}{765}) + (\_\_\_\_)]$ = 8580 lbs

$F_{yc} = C_{yc}$ ______ = ______ = 0 lbs

$M_c = C_{xyc}$ ______ = ______ = 0 ft-lbs

$F_{xw} = C_{xw}$ ______ = ______ = 0 lbs

$F_{yw} = C_{yw}$ 1.99×10^5 = ______ = 199,000 lbs

$M_w = C_{xyw}$ 1.52×10^8 = ______ = -5.3×10^6 ft-lbs

$F_\ell = F_{xc} + F_{xw}$ = 8580 + ______ = 8580 lbs

$F_t = F_{yc} + F_{yw}$ = ______ + ______ = 199,000 lbs

$M = M_c + M_w - (F_t\ \text{ARM})$ = $0 + -5.3 \times 10^6 - (199{,}000 \times 394)$ = -83.7×10^6 ft-lbs

a) If M equals zero, the equilibrium position has been found.

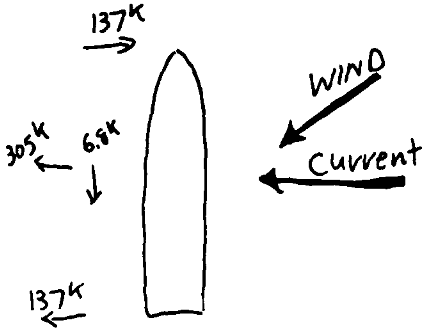
$F_H = \sqrt{F_\ell^2 + F_t^2}$ = ______ = ______ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)
Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

LHA-1 1.5 Knot Current, 28 Knot WIND

C. TRIAL # LHA-1 $^{WD}/T$ = 2.6



WIND/CURRENT ANGLE θ_T = ____ °

*CURRENT ANGLE θ_c = 90 °

*WIND ANGLE θ_w = 60 °

*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or −) of Forces and Moments.

Coefficients for this θ_c, θ_w and $^{WD}/T$:

C_{xca} = 0. (Figure 2)

C_{yc} = 1.3 (Figure 3)

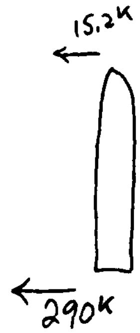
C_{xcb} = $|C_{yc} \text{ Cos } \theta_c| \text{Cos } \theta_c$ = ____ = 0.

C_{xyc} = 0. (Figure 4)

C_{xw} = 0.23 (Figure 5) __Normal, or X Hull-Dominated

C_{yw} = 0.86 (Figure 6)

C_{xyw} = 0.055 (Figure 7)



Forces and Moments:

$F_{xc} = 1/2\, \rho_c V_c^2 \left[\left(C_{xca}\, S \frac{B}{LWL}\right) + \left(C_{xcb} A_b\right)\right]$

F_{xc} = 1/2 (1.9875) (2.53)^2 [(0.) + (0.)] = 0. lbs

F_{yc} = C_{yc} 1.3 × 1.04×10^5 = ____ = 135,000 lbs

M_c = C_{xyc} 7.9×10^7 × 0 = ____ = 0 ft-lbs

F_{xw} = C_{xw} 2.98×10^4 = 2.98×10^4 (0.23) = 6850 lbs

F_{yw} = C_{yw} 1.99×10^5 = 0.86 (1.99×10^5) = 171,000 lbs

M_w = C_{xyw} 1.52×10^8 = 0.055 (1.52×10^8) = 8,350,000 ft-lbs

F_ℓ = F_{xc} + F_{xw} = 0 + 6850 = 6850 lbs

F_t = F_{yc} + F_{yw} = 135,000 + 171,000 = 305,000 lbs

$M = M_c + M_w - (F_t \text{ ARM})$ = 0 + 8,350,000 − 305,000 (394) = −112×10^6 ft-lbs

a) If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_\ell^2 + F_t^2}$ = ____ = ____ lbs

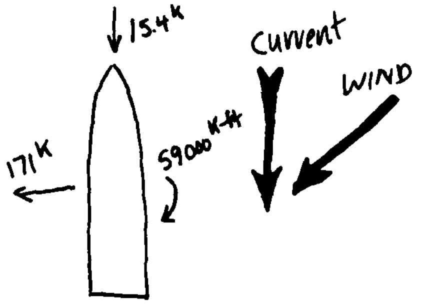
b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)

Sample Calculation Procedure for Single Hulled Vessels - Blank Form

1.5 Knot Current, 28 Knot WIND

C. TRIAL # LHA-1 $^{WD}/T$ = 2.6



WIND/CURRENT ANGLE θ_T = ______ °

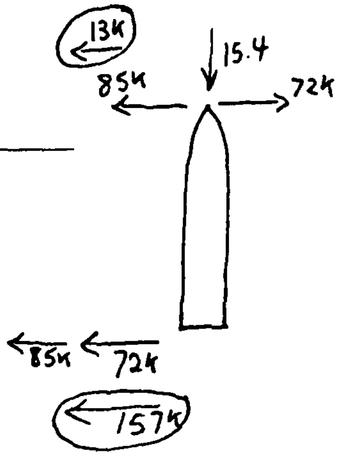
*CURRENT ANGLE θ_c = 0 °

*WIND ANGLE θ_w = 60 °

*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.

Coefficients for this θ_c, θ_w and $^{WD}/T$:



C_{xca} = 0.35 (Figure 2)

C_{yc} = 0. (Figure 3)

C_{xcb} = $|C_{yc} \cos \theta_c| \cos \theta_c$ = ______ = 0.

C_{xyc} = 0 (Figure 4)

C_{xw} = 0.24 (Figure 5) _Normal, or X Hull-Dominated

C_{yw} = 0.86 (Figure 6)

C_{xyw} = 0.055 (Figure 7)

Forces and Moments:

$F_{xc} = 1/2\, \rho_c\, V_c^2\, [(C_{xca}\, S\, \frac{B}{LWL}) + (C_{xcb}\, A_b)]$

$F_{xc} = 1/2\, (1.9876)\, (2.53)^2\, [(0.35 \times 27{,}700\, \frac{106}{765}) + (0)]$ = 8,600 lbs

$F_{yc} = C_{yc}$ ______ = ______ = 0 lbs

$M_c = C_{xyc}$ ______ = ______ = 0 ft-lbs

$F_{xw} = C_{xw}$ ______ = ______ = 6850 lbs

$F_{yw} = C_{yw}$ ______ = ______ = 171,000 lbs

$M_w = C_{xyw}$ ______ = ______ = 8,350,000 ft-lbs

$F_\ell = F_{xc} + F_{xw}$ = 8600 + 6850 = 15,400 lbs

$F_t = F_{yc} + F_{yw}$ = 0 + 171,000 = 171,000 lbs

$M = M_c + M_w - (F_t\ \text{ARM})$ = 0 + 8,350,000 − (171,000 × 394) = -59×10^6 ft-lbs

a) If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_\ell^2 + F_t^2}$ = ______ = ______ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)
Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

2 knot current, 35 knot WIND

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Ship Designation : LHA-1

Water Depth WD = 55 feet

(_ @ High Tide or _ @ Low Tide)

*Current Speed V_c = (2) knots x 1.689 = 3.3 ft/sec

(Use average value of current profile between waterline and ship's keel)

*Wind Speed V_w = (40.3) mph x 1.467 = 59 ft/sec

(@ 33 feet above water level)

(35 knots)

* If current speed and wind speed are unknown, refer to Table 1.
In calculations below, use ft/sec quantities.

ASSUMPTIONS

a) Water density is constant and equals 1.9876 $lb\text{-}sec^2/ft^4$ @ 68°F.

b) Air density is constant and equals 0.00237 $lb\text{-}sec^2/ft^4$ @ 68°F.

PROCEDURE

A. From Table 2:

Length Overall LOA = 820 feet

Length at waterline LWL = 765 feet

Beam B = 106 feet

_ Normal

X Hull-Dominated

Load condition:		Fully Loaded _		1/3 Stores/Cargo /Ballasted _		Light _	
Draft	T =		feet	21.3	feet		feet
Below water end area	A_b=BT =		sq.ft.	21000	sq.ft.		sq.ft.
End-projected wind area	A_e =		sq.ft.	11250	sq.ft.		sq.ft.
Side-projected wind area	A_s =		sq.ft.	74950	sq.ft.		sq.ft.
Displacement	D =		long tons	30020	long tons		long tons

B. Basic constants:

ARM = 0.48 LOA = 394 feet

**S = $(1.7\ T\ LWL) + (\frac{35D}{T})$ = 27,700 sq.ft.

** For a normal vessel S should be multiplied by a factor of 0.95.

$F_{yc} = C_{yc}\ 1/2\ \rho_c\ V_c^2\ LWL\ T = C_{yc}\ 1/2\ (1.9876)\ (3.3)^2\ 765\ (21.3) = C_{yc}\ 1.77 \times 10^5$

$M_c = C_{xyc}\ 1/2\ \rho_c\ V_c^2\ LWL^2\ T = C_{xyc}\ 1/2\ (1.9876)\ (3.3)^2\ (765)^2\ 21.3 = C_{xyc}\ 1.36 \times 10^8$

$F_{xw} = C_{xw}\ 1/2\ \rho_w\ V_w^2\ A_e = C_{xw}\ 1/2\ (0.00237)\ (59)^2\ 11250 = C_{xw}\ 4.64 \times 10^4$

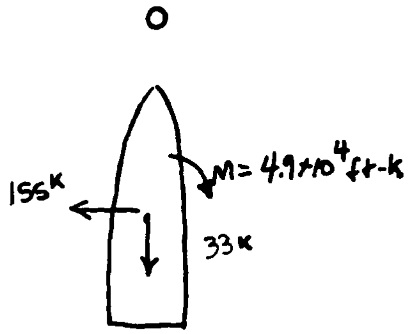
$F_{yw} = C_{yw}\ 1/2\ \rho_w\ V_w^2\ A_s = C_{yw}\ 1/2\ (0.00237)\ (59)^2\ 74950 = C_{yw}\ 3.09 \times 10^5$

$M_w = C_{xyw}\ 1/2\ \rho_w\ V_w^2\ A_s\ LWL = C_{xyw}\ 1/2\ (0.00237)\ (59)^2\ 74950\ (765) = C_{xyw}\ 2.37 \times 10^8$

FIGURE 8a
Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

2 knot Current, 35 knot WIND

C. TRIAL # ______ $^{WD}/T$ = 2.6



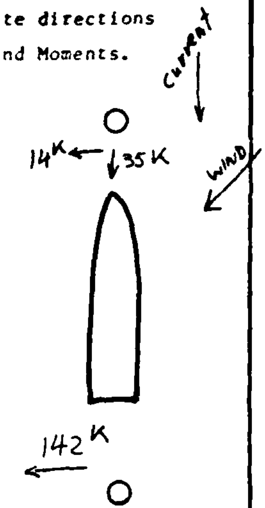
WIND/CURRENT ANGLE θ_T = ______ °

*CURRENT ANGLE θ_c = 0 °

*WIND ANGLE θ_w = 30 °

*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or −) of Forces and Moments.



Coefficients for this θ_c, θ_w and $^{WD}/T$:

C_{xca} = 0.35 (Figure 2)

C_{yc} = 0.0 (Figure 3)

C_{xcb} = $|C_{yc}\ \mathrm{Cos}\ \theta_c|\ \mathrm{Cos}\ \theta_c$ = 0. = ______

C_{xyc} = 0.0 (Figure 4)

C_{xw} = 0.39 (Figure 5) __Normal, or X Hull-Dominated

C_{yw} = 0.5 (Figure 6)

C_{xyw} = 0.05 (Figure 7)

Forces and Moments:

$F_{xc} = 1/2\ \rho_c\ V_c^2\ [(C_{xca}\ S\ \frac{B}{LwL}) + (C_{xcb}\ A_b)]$

F_{xc} = 1/2 (1.9876) (3.3)^2 [(0.35 × 27700 × $\frac{106}{765}$)+(0.)] = 14,600 lbs

$F_{yc} = C_{yc}$ 1.77×10^5 = ______ = 0 lbs

$M_c = C_{xyc}$ 1.36×10^8 = ______ = 0 ft-lbs

$F_{xw} = C_{xw}$ 4.64×10^4 = ______ = 18,100 lbs

$F_{yw} = C_{yw}$ 3.09×10^5 = ______ = 155,000 lbs

$M_w = C_{xyw}$ $0.05 \times 2.37\times10^8$ = ______ = 1.19×10^7 ft-lbs

$F_\ell = F_{xc} + F_{xw}$ = 14,600 + 18,100 = 33,000 lbs

$F_t = F_{yc} + F_{yw}$ = 0 + 155,000 = 155,000 lbs

$M = M_c + M_w - (F_t\ \mathrm{ARM})$ = $1.19\times10^7 - (1.55\times10^5 \times 394)$ = -4.9×10^7 ft-lbs

a) If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_\ell^2 + F_t^2}$ = ______ = ______ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)

Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

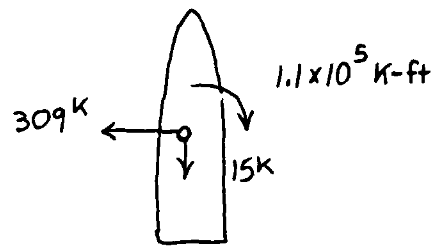
2 knot current, 35 knot WIND

C. TRIAL # ______ $^{WD}/_T$ = 2.6

WIND/CURRENT ANGLE θ_T = ______ °

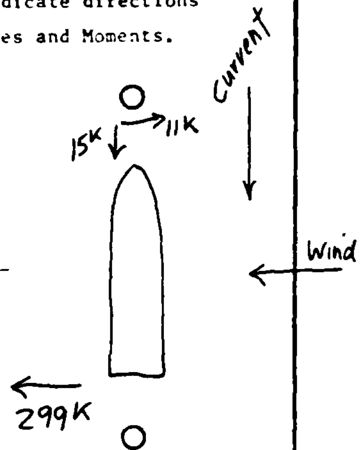
*CURRENT ANGLE θ_c = 0 °

*WIND ANGLE θ_w = 90 °



*θ_c and θ_w are measured clockwise from ship's bow.

Note: Use sketch to indicate directions (+ or -) of Forces and Moments.



Coefficients for this θ_c, θ_w and $^{WD}/T$:

C_{xca} = 0.35 (Figure 2)

C_{yc} = 0. (Figure 3)

C_{xcb} = $|C_{yc}\ \mathrm{Cos}\ \theta_c|\mathrm{Cos}\ \theta_c$ = 0. = ______

C_{xyc} = 0.0 (Figure 4)

C_{xw} = 0.0 (Figure 5) __Normal, or __Hull-Dominated

C_{yw} = 1.0 (Figure 6)

C_{xyw} = −0.035 (Figure 7)

Forces and Moments:

$F_{xc} = 1/2\ \rho_c\ V_c^2\ [(C_{xca}\ S\ \frac{B}{LWL}) + (C_{xcb}\ A_b)]$

$F_{xc} = 1/2\ (1.9876)\ (3.3)^2\ [(0.35 \times 27700\ \frac{106}{765}) + (\ \ )]$ = 14,600 lbs

$F_{yc} = C_{yc}$ ______ = ______ = 0 lbs

$M_c = C_{xyc}$ ______ = ______ = 0 ft-lbs

$F_{xw} = C_{xw}$ 4.64×10^4 = ______ = 0 lbs

$F_{yw} = C_{yw}$ 3.09×10^5 = ______ = 309,000 lbs

$M_w = C_{xyw}$ 2.37×10^8 = $-0.035 \times 2.37 \times 10^8$ = 8.3×10^6 ft-lbs

$F_\ell = F_{xc} + F_{xw}$ = 14,600 + 0 = 14,600 lbs

$F_t = F_{yc} + F_{yw}$ = 0 + 309,000 = 309,000 lbs

$M = M_c + M_w - (F_t\ \mathrm{ARM})$ = $0 + 8.3 \times 10^6 - (3.1 \times 10^5 \times 394)$ = -114×10^6 ft-lbs

a) If M equals zero, the equilibrium position has been found.

$F_H = \sqrt{F_\ell^2 + F_t^2}$ = ______ = ______ lbs

b) If M is a large positive or negative number, the vessel is not in equilibrium and a different ship position angle must be tried (i.e., modify θ_c and θ_w so that the ship is in a different position with respect to wind and current vectors).

FIGURE 8a (Continued)

Sample Calculation Procedure for Single-Hulled Vessels - Blank Form

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